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a systematic review

Stavropoulos, Andreas; Bertl, Kristina; Eren, Sera; Gotfredsen, Klaus

Published in:
Clinical Oral Implants Research

DOI:
10.1111/clr.13499

Publication date:
2019

Document version
Publisher's PDF, also known as Version of record

Received: 1 January 2019 | Revised: 6 April 2019 | Accepted: 18 June 2019

DOI: 10.1111/clr.13499

REVIEW ARTICLE

CLINICAL ORAL IMPLANTS RESEARCH WILEY

Mechanical and biological complications after implantoplasty—A systematic review

Andreas Stavropoulos[1,2] | Kristina Bertl[1,3] | Sera Eren[4] | Klaus Gotfredsen[5]

[1]Department of Periodontology, Faculty of Odontology, University of Malmö, Malmö, Sweden

[2]Division of Conservative Dentistry and Periodontology, University Clinic of Dentistry, Medical University of Vienna, Vienna, Austria

[3]Division of Oral Surgery, University Clinic of Dentistry, Medical University of Vienna, Vienna, Austria

[4]Postgraduate Course Periodontology, Medical University of Vienna, Vienna, Austria

[5]Department of Oral Rehabilitation, Faculty of Health and Medical Sciences, School of Dentistry, University of Copenhagen, Copenhagen, Denmark

Correspondence
Andreas Stavropoulos, Department of Periodontology, Faculty of Odontology, University of Malmö, Carl Gustafs väg 34, 20506 Malmö, Sweden.
Email: andreas.stavropoulos@mau.se

Funding information
KOF/Calcin Foundation of the Danish Dental Association; Austrian Society of Implantology (ÖGI)

Abstract

Objectives: Implantoplasty, that is, the mechanical modification of the implant, including thread removal and surface smoothening, has been proposed during surgical peri-implantitis treatment. Currently, there is no information about any potential mechanical and/or biological complications after this approach. The aim of the current review was to systematically assess the literature to answer the focused question "Are there any mechanical and/or biological complications due to implantoplasty?".

Materials and methods: A systematic literature search was performed in three databases until 23/09/2018 to assess potential mechanical and/or biological complications after implantoplasty. All laboratory, preclinical in vivo, and clinical studies involving implantoplasty were included, and any complication potentially related to implantoplasty was recorded and summarized.

Results: Out of 386 titles, 26 publications were included in the present review (six laboratory, two preclinical in vivo, and 18 clinical studies). Laboratory studies have shown that implantoplasty does not result in temperature increase, provided proper cooling is used, but leads in reduced implant strength in "standard" dimension implants; further, preclinical studies have shown titanium particle deposition in the surrounding tissues. Nevertheless, no clinical study has reported any remarkable complication due to implantoplasty; among 217-291 implants subjected to implantoplasty, no implant fracture was reported during a follow-up of 3–126 months, while only a single case of mucosal discoloration, likely due to titanium particle deposition, has been reported.

Conclusions: Based on all currently available, yet limited, preclinical in vivo and clinical evidence, implantoplasty seems not associated with any remarkable mechanical or biological complications on the short- to medium-term.

KEYWORDS

complication, implant threads, implantoplasty, peri-implantitis, systematic review

1 | INTRODUCTION

It is currently accepted that treatment of peri-implantitis regularly requires surgical intervention to get adequate access to the contaminated implant surface (Klinge, Klinge, Bertl, & Stavropoulos, 2018; Renvert & Polyzois, 2018). Indeed, a variety of protocols, including mechanical or chemical means, or combinations thereof, aiming at implant surface decontamination have been proposed.

Systematic reviews of studies on the various clinically applicable decontamination protocols, however, have shown that (a) complete implant surface decontamination cannot be achieved, neither by mechanical nor chemical means alone, not even under laboratory (in vitro) settings, (b) in general, combinations of mechanical and chemical means appeared more effective, (c) there is large variation in the effectiveness of the various approaches, among other reasons, depending on the type of implant surface micro-structure, and (d) the more structured the implant surface, the more difficult is it to decontaminate (Louropoulou, Slot, & Van der Weijden, 2014; Ntrouka, Slot, Louropoulou, & Van der Weijden, 2011). In this context, preclinical in vivo studies have shown that differences in implant surface micro-structure may indeed influence disease progression rate and the outcome of treatment in terms of extent/severity of residual peri-implant inflammation. Specifically, peri-implantitis progresses faster at rough implants compared with machined-surface implants and there is a variation in progression rate among the various microstructures (Albouy, Abrahamsson, Persson, & Berglundh, 2008; Berglundh, Gotfredsen, Zitzmann, Lang, & Lindhe, 2007; Carcuac et al., 2013), while there are remarkable differences in the size of the residual inflammatory infiltrate (i.e., from relatively small to quite large) and in the distance of the infiltrate to the bone (i.e., from relatively far away to almost in contact), among implants with similar surface roughness (i.e., moderately rough), but of different microstructural design (Albouy, Abrahamsson, Persson, & Berglundh, 2011). In this latter study, the least residual inflammatory infiltrate—which was also located furthest from the bone (i.e., 1 mm)—was observed around implants with a machined surface.

One approach suggested to address effectively the above-mentioned concerns associated with rough implants affected by peri-implantitis, is implantoplasty, that is, the mechanical removal (grinding) of the implant threads and the rough implant surface, rendering thus a relatively "smooth" implant surface. Implantoplasty is performed at the aspects of the implant, where due to defect anatomy only a limited potential for bone regeneration and/or re-osseointegration after healing can be expected, that is, the supra-bony or dehiscenced aspects of the implant. Indeed, a few clinical studies have reported successful clinical and radiographic outcomes after surgical treatment of peri-implantitis combined with implantoplasty (Matarasso, Iorio Siciliano, Aglietta, Andreuccetti, & Salvi, 2014; Pommer et al., 2016; Romeo et al., 2005; Romeo, Lops, Chiapasco, Ghisolfi, & Vogel, 2007; Schwarz, Hegewald, John, Sahm, & Becker, 2013; Schwarz, Sahm, Iglhaut, & Becker, 2011). Nevertheless, perforation of the implant body, destruction of the implant-abutment connection, overheating of the implant during grinding causing thermal damage to the surrounding bone, or induction of mucosal staining and/or increased risk for late inflammatory reactions due to titanium particle deposition, generated from the grinding procedure, appear as reasonable concerns. Further, reduction of the implant mass (implant diameter) at its coronal aspect, occasionally also involving the implant collar (Figure 1), may compromise implant strength and lead to an increased rate of late mechanical complications, for example, implant collar deformation, loosening of the supra-structure, fixation-screw fracture, and implant fracture; this may, in turn, lead to recurrent peri-implant biological complications and/or require explantation. Currently, there is only limited information on this topic and there is no comprehensive systematic appraisal of possible complications associated with implantoplasty.

Thus, the aim of the current review was to systematically assess the literature to answer the focused question "Are there any mechanical and/or biological complications due to implantoplasty?".

2 | MATERIAL AND METHODS

2.1 | Protocol and eligibility criteria

The present systematic review was performed according to the criteria of the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA; Appendix S1; Liberati et al., 2009; Moher, Liberati, Tetzlaff, & Altman, 2009). The following inclusion criteria

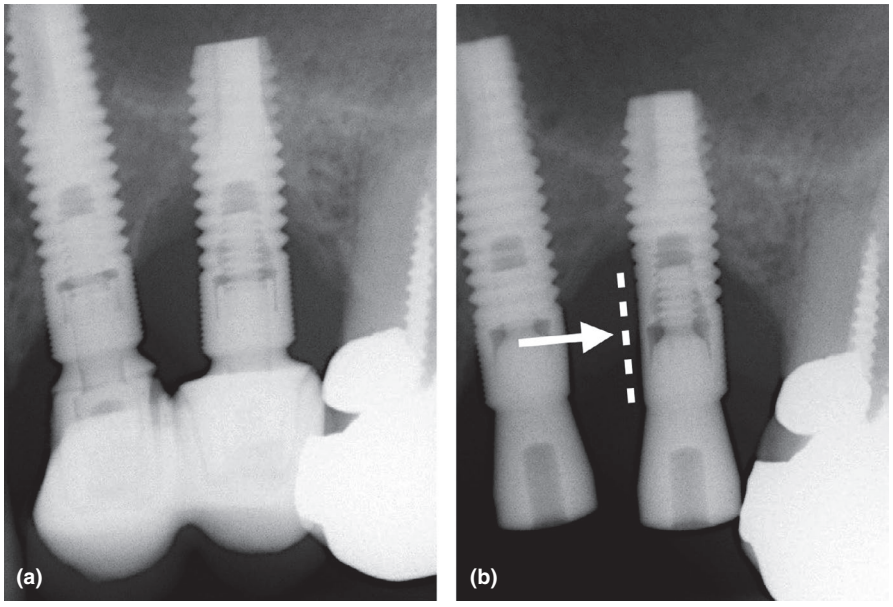

FIGURE 1 (a and b) Clinical case from authors' clinic illustrating that implantoplasty often results in significant reduction in implant wall thickness, occasionally involving also the collar (white arrow and line)

were applied during literature search on original studies without publication year restriction: (a) English or German language; (b) laboratory (in vitro), preclinical in vivo, or clinical trials; (c) reporting on dental implants subjected to implantoplasty; (d) in case of preclinical in vivo and clinical trials, ≥1 month follow-up after peri-implantitis surgery; and (e) full text available.

2.2 | Information sources and literature search

Electronic search was performed on three sources (last search 23/09/2018; no date restriction used): MEDLINE (PubMed), Scopus (Ovid), and CENTRAL (Ovid). The database MEDLINE (PubMed) was searched with the following keywords: (periimplant* OR peri-implant*) AND (implantoplasty OR implant surface decontamination OR implant surface debridement OR implant surface modification OR implant surface detoxification OR implant threads). The asterisk (*) was used as a truncation symbol. For the other two databases, comparable terms were used, but modified to suit specific criteria of the particular database. Additionally, a screening of the reference lists and a forward search via Science Citation Index of the included papers was performed. Grey literature was searched for in opengrey.eu and is reported under other sources.

2.3 | Data collection and extraction

Two authors (SE and KB) independently checked title, abstract, and finally full text on the predefined eligibility criteria. Abstracts with unclear methodology were included in full-text assessment to avoid exclusion of potentially relevant articles. One author (SE) repeated the literature search. Kappa scores regarding agreement on the articles to be included in the full-text analysis and those finally chosen were calculated. In case of ambiguity, consensus through discussion was achieved together with a third author (AS). Further, two authors (SE and KB) extracted twice the following data (if available): author; year of publication; design and aim of the study; inclusion criteria; numbers of animals/patients; implant-related details [i.e., number,

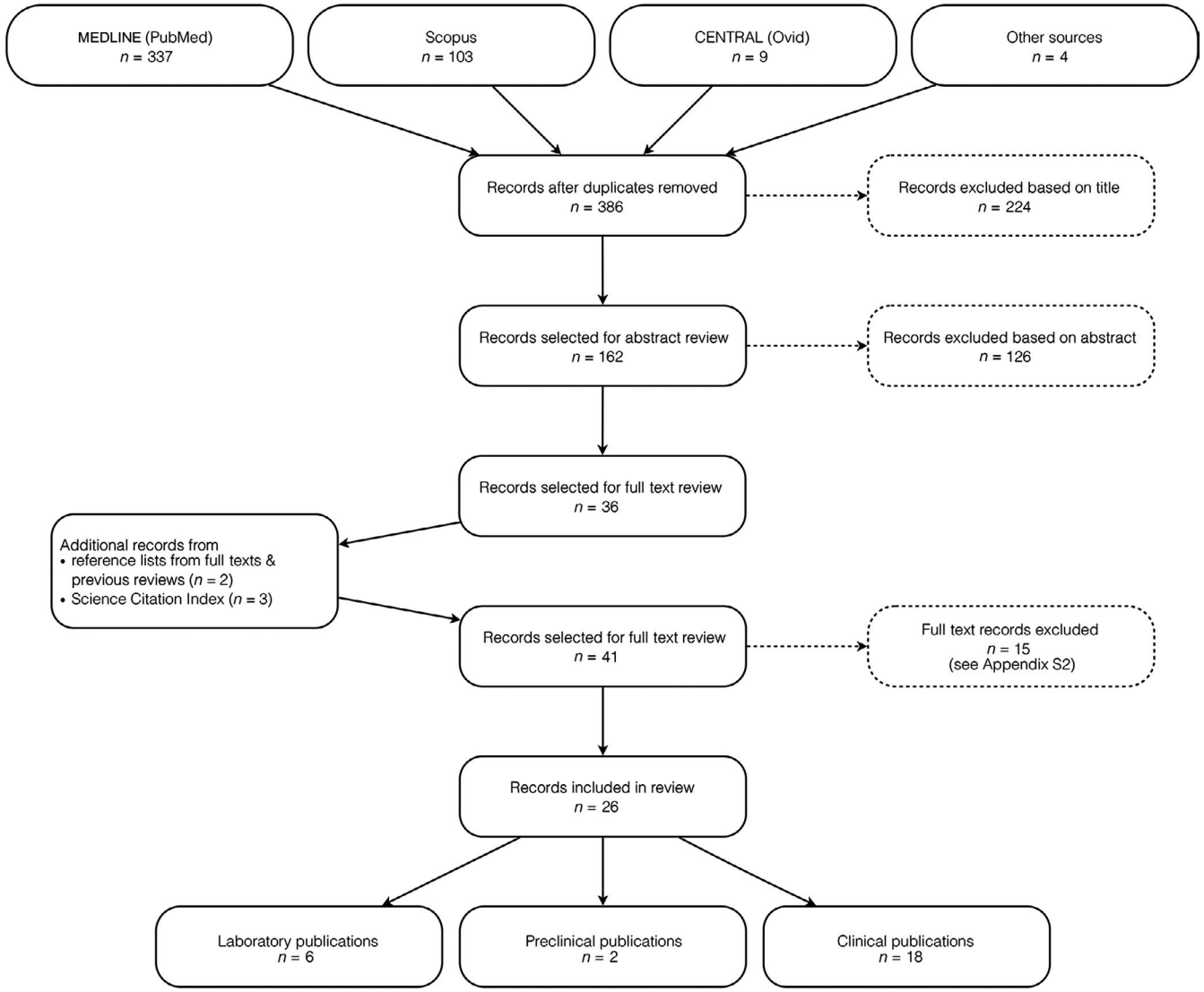

FIGURE 2 Flow chart of the literature search

TABLE 1 Characteristics of the 6 included laboratory publications

Study (Year)	Aim	Implant details: a. Type (Company) b. Dimension (mm; *n*) c. Surface d. Connection (*n*) e. Exposed implant surface (mm)	IP details: a. Bur b. Speed c. Cooling	No. of implants: a. With IP (test) b. Without IP (control)	Method details
Biomechanical analyses					
Chan et al. (2013)	1. Risk of fracture after IP 2. Effect of implant diameter	a. Tapered TRI Vent (TRI Dental Implants), squared thread design b. 3.75 × 10 (16), 4.7 × 10 (16) c. Blasted with zirconia oxide d. Internal hexagon e. 5	a. Diamond (30 and 15 μm, egg-shaped) > Arkansas > fine silicone polisher (manually) b. 15,000 rpm c. NR	a. 16 b. 16 (8/diameter)	Embedded in acrylic resin, 30° angulation (20° abutment + 10° metal jig) Loading with 0.5 mm/min crosshead speed until fracture (bending & fracture strength) SEM to assess mode of fracture
Gehrke et al. (2016)	1. Risk of fracture after IP 2. Effect of implant connection	a. Conical implants (Implacil de Bortoli) b. 4 × 11 c. NR d. 3 different connection types: external hexagon (20), internal hexagon (20), morse taper (20) e. 5	a. Conical carbide (standardized drilling, 0.05 μm/min) b. 20,000 rpm c. No cooling	a. 30 b. 30 (10/connection type)	Assessment of implant diameter 30° angulation Loading with 1 mm/min crosshead speed until fracture (resistance force) Low-power magnification to assess mode of fracture
Costa-Berenguer (2018)	1. Risk of fracture after IP	a. Screw-shaped titanium grade IV implants (Titamax Smart Cortical, Neodent), V-shaped threads b. 4.1 (platform)/4.0 (body) × 13 c. Sandblasted and acid-etched d. External hexagon e. 6	a. Tungsten carbide (oval-shaped) > 2 silicon carbide polisher (manually) b. High-speed handpiece c. "Abundant"	a. 10 b. 10	Assessment of implant diameter Embedded in bone-like resin (≥3 GPa), 30° angulation Loading with 1 mm/min crosshead speed until fracture (resistance force) SEM to assess mode of fracture
Finite element analyses					
Tribst et al. (2017)	1. Stress distribution after IP on implant, retention screw & bone tissue 2. Effect of different amounts of exposed implant surface	a. Model of bone level tapered implants (Straumann) b. 4.1 × 10 c. NR d. Internal e. 0–1–2–3–4–5–6	Simulated IP	Each bone loss height (i.e., 1–6 mm) was simulated with & without IP	Axial load (300 N) on the cusp Effect (Von Mises stress and strain) on implant, retention screw & bone tissue tested

(Continues)

TABLE 1 (Continued)

Study (Year)	Aim	Implant details: a. Type (Company) b. Dimension (mm; *n*) c. Surface d. Connection (*n*) e. Exposed implant surface (mm)	IP details: a. Bur b. Speed c. Cooling	No. of implants: a. With IP (test) b. Without IP (control)	Method details
Heat production analyses					
Sharon et al. (2013)	1. Heat production during IP 2. Effect of bur type	a. Biocom (MIS Implants) b. NR c. Sandblasted and acid-etched d. NR e. NR	a. 4 different burs: diamond "premium line" (medium grains), diamond (medium grains), carbide, smooth (control) b. 340,000 rpm c. 25 ml/min	a. NR b. 0	A canal was prepared in the apical part of each implant through its vertical axis for the electrodes IP performed for 60 s with standardized pressure (100 g)
de Souza Júnior et al. (2016)	1. Heat production during IP 2. Effect of bur type	a. Easy Porous (Conexão Sistemas de Protése) b. NR c. Dual acid-etched d. External hexagon e. NR	a. 3 different burs (cylindrical shape): diamond, tungsten carbide & multilaminar b. 350,000 rpm c. 20 ml/min	a. 36 b. 0	IP on a standardized area of 14 mm^2 with standardized pressure (100 g) Temperature assessment at the implant & in 1 mm distance in the bone

Note: IP, implantoplasty; NR, not reported; SEM, scanning electron microscope.

type (company/system), dimensions, surface, connection, jaw location, exposed implant surface, prosthetic restoration]; details related to implantoplasty (i.e., bur type, bur speed, use and type of cooling, cleaning procedure after implantoplasty); complications directly related to implantoplasty, for example, perforation of the implant body, destruction of implant-abutment connection, implant loss shortly after peri-implantitis surgery due to overheating, and induction of mucosal staining due to titanium particle deposition; follow-up period; late complications likely related to implantoplasty, for example, implant collar deformation, repeated loosening of the supra-structure, fixation-screw fracture, implant fracture, and inflammation due to titanium particle deposition; and any other complication. If not specifically reported, data/values were calculated from graphs/tables included in the publications, where deemed relevant.

2.4 | Synthesis of results

The results of the included studies were summarized and pooled whenever possible.

2.5 | Methodological and reporting quality assessment

Due to the specific research question herein, aiming to summarize any reported complication after implantoplasty, irrespective of the aim of the individual studies, or the clinical outcome of the evaluated interventions, no study quality assessment was performed.

3 | RESULTS

3.1 | Study selection

The flow chart of the literature search is presented in Figure 2. Kappa scores regarding agreement on the articles to be included in the full-text analysis and those finally chosen were 0.91 and 0.95, respectively ($p < 0.001$). Out of a total of 391 records assessed, 26 publications were finally included: six laboratory (Chan et al., 2013; Costa-Berenguer et al., 2018; Gehrke, Aramburú Júnior, Dedavid, & Shibli, 2016; Sharon, Shapira, Wilensky, Abu-Hatoum, & Smidt, 2013; de Souza Júnior et al., 2016; Tribst, Piva, Shibli, Borges, & Tango, 2017), two preclinical in vivo (Schwarz, Mihatovic, Golubovic, Becker, & Sager, 2014; Schwarz, Sahm, Mihatovic, Golubovic, & Becker, 2011), and 18 clinical publications (Englezos, Cosyn, Koole, Jacquet, & De Bruyn, 2018; Geremias et al., 2017; Matarasso et al., 2014; Nart, de Tapia, Pujol, Pascual, & Valles, 2018; Pommer et al., 2016; Ramanauskaite, Becker, Juodzbalys, & Schwarz, 2018; Romeo et al., 2005; Sapata, de Souza, Sukekava, Villar, & Neto, 2016; Schwarz et al., 2013; Schwarz, John, & Becker, 2015; Schwarz, John, Mainusch, Sahm, & Becker, 2012; Schwarz, John, Sahm, & Becker, 2014; Schwarz, John, Schmucker, Sahm, & Becker, 2017; Schwarz, Sahm, & Becker, 2014; Schwarz, Sahm, Iglhaut, et al., 2011; Suh, Simon, Jeon, Choi, & Kim, 2003; Thierbach & Eger, 2013). The two preclinical in vivo publications (Schwarz, Mihatovic, et al., 2014; Schwarz, Sahm, Mihatovic, et al.,

TABLE 2 Results of the 6 included laboratory publications

Study (Year)	Results after IP
Biomechanical analyses	
Chan et al. (2013)	1. All 3.75-mm implants fractured at implant body; IP reduced ss the bending strength by 17% from 614 to 511 N, but did not affect ss fracture strength (322 vs. 325 N for IP and controls, respectively). Cracks developed from the implant platform 2. For 4.7-mm implants bending (803 N) and fracture (430 N) strength were not affected by IP; fractures occurred only at the abutment screw
Gehrke et al. (2016)	1. Mean final diameter: external hexagon (3.1 mm/22% reduction) > internal hexagon (3.2 mm/19% reduction) > morse taper (3.3 mm/19% reduction) 2. Mean fracture strength was ss reduced: internal hexagon (496 N/40% reduction) > external hexagon (487 N/37% reduction) > morse taper (718 N/20% reduction) 3. Increased variation of the fracture strength after IP
Costa-Berenguer (2018)	1. Minimal reduction of the implant's inner body diameter (0.2 mm) 2. No ss differences in the resistance force between test & control group (896 and 880 N, respectively) 3. All test and 5 control specimens fractured at the implant body, 5 control specimens fractured at the abutment screw
Finite element analyses	
Tribst et al. (2017)	1. Von Mises stress on the implant: The stress increase on the implant body due to IP, ranged from 44% to 85%, but it was more or less independent of the extent—in height—of implant grinding 2. Von Mises stress on the retention screw: The stress increase on the retention screw due to IP ranged from 0% to 35% and in general stress increased with the extent—in height—of implant grinding 3. Bone micro-strain within the bone tissue: Micro-strain on peri-implant bone tissue depended on the extent of simulated bone loss but not on IP; micro-strain was critical when the endo-osseous portion of the implant was smaller than the exposed portion
Heat production analyses	
Sharon et al. (2013)	1. Under proper cooling conditions, only minimal thermal changes (1.5–1.8°C), which represent no risk for the surrounding soft and hard tissues, were recorded for all type of burs; there were no ss differences among different burs
de Souza Júnior et al. (2016)	1. Mean temperature increase at the implant: diamond (4.7°C) > multilaminar (2.5°C) > tungsten carbide (1.1°C; ss differences among the groups; tungsten carbide smallest variation) 2. Mean temperature increase in the bone: diamond (1.4°C) > multilaminar (1.0°C) > tungsten carbide (0.9°C; no ss differences among groups; multilaminar smallest variation)

Abbreviations: IP, implantoplasty; NR, not reported; ss, statistically significant.

2011) and the clinical of Romeo et al. (2005) and Romeo et al. (2007) publications reported on different aspects basically of the same study population. Further, the publications of Schwarz et al. (2013), Schwarz et al. (2012), Schwarz et al. (2017) are follow-ups of the study population presented in Schwarz, Sahm, Iglhaut, et al. (2011)), and some of the patients included in Schwarz, Sahm, Iglhaut, et al. (2011)) were also included in Ramanauskaite et al. (2018).

3.2 | Study characteristics, populations, and interventions

Tables 1, 3, and 4 present study characteristics of the included laboratory, preclinical in vivo, and clinical publications, respectively.

3.2.1 | Laboratory studies

Three studies (Chan et al., 2013; Costa-Berenguer et al., 2018; Gehrke et al., 2016) reported on implant strength to resist fracture after implantoplasty, based on altogether 56 implants of different diameters and connection types subjected to implantoplasty versus 56 intact implants. One study (Tribst, et al.) assessed stress distribution after implantoplasty on the implant components and surrounding tissue in relation to the extent of exposed implant surface, by means of finite element analysis. Finally, two studies (Sharon et al., 2013; de Souza Júnior et al., 2016) measured heat production during implantoplasty at the implant and surrounding bone, using different types of burs.

3.2.2 | Preclinical in vivo studies

Two publications (Schwarz, Mihatovic, et al., 2014; Schwarz, Sahm, Mihatovic, et al., 2011) report on the same study including 48 non-loaded implants installed in six beagle dogs, out of which 24 were subjected to implantoplasty. Assessment of complications included clinical observations after surgery and histological analysis at the end of the study.

3.2.3 | Clinical studies

Eighteen clinical publications (six RCTs, five prospective case series, four case reports, and three retrospective analyses) report on 217–291 implants subjected to implantoplasty and on 129 implants

TABLE 3 Characteristics and results of the 2 included preclinical publications

Study (Year)	Model details: a. Animal (type, no.) b. No. of implants with/without IP c. Follow-up period (months)	Implant details: a. Type (Company) b. Dimension (mm)	IP details: a. Bur b. Cooling	Complication type & rate
Schwarz, Sahm, Mihatovic, et al. (2011) and Schwarz, Mihatovic, et al. (2014)[a]	a. Dog (beagle, 6) b. 24 (at supracrestal aspects) /24 c. 3 (submerged/non-loaded)	a. Camlog® Screw-Line Implant, Promote® plus (Camlog Biotechnologies AG) b. 3.8 × 11	a. Diamond > Arkansas b. "copious irrigation with saline solution"	1. No complications such as allergic reactions, swellings, abscesses, or infections were observed 2. Histological analysis revealed a slight to moderate deposition of titanium particles in the adjacent tissues, which was associated with a localized inflammatory cell infiltrate

Abbreviation: IP, implantoplasty.

[a]Data are based on the same animals.

without implantoplasty, in 288–327 patients [variation in number of implants/patients is due to uncertainty regarding the number of patients in the study of Ramanauskaite et al., 2018 included also in Schwarz, Sahm, Iglhaut, et al. (2011)] and regarding the number of implants treated with implantoplasty in the study of Thierbach & Eger, 2013); the follow-up ranged between 3 and 126 months, with 2/3 of the publications having a follow-up ≤36 months. The type of burs used for implantoplasty is reported in 16 publications, while other details, for example, revolutions per minute, were only sparsely reported.

3.3 | Summary of results and reported complications

Tables 2, 3, and 4 present study results and reported complications of the included laboratory, preclinical in vivo, and clinical publications, respectively.

3.3.1 | Laboratory studies

Implantoplasty did not affect significantly implant strength and resistance to fracture of wide diameter implants (i.e., 4.7 mm diameter; Chan et al., 2013). In contrast, variable results were reported for narrow/regular diameter implants (i.e., 3.75–4.1 mm diameter); in one study, a minimal reduction (i.e., 0.2 mm) in the core diameter of the implant did not significantly affect implant strength (Costa-Berenguer et al., 2018), while average strength reduction of about 17%–40%—depending on implant platform/connection design—was observed in two other studies (Chan et al., 2013; Gehrke et al., 2016). In a finite element analysis (Tribst et al., 2017), implantoplasty resulted in a stress increase on the implant body of 44%–85%, more or less independent of the extent of simulated bone loss height, thus also of the extent—in height—of implant grinding; implantoplasty did not affect bone micro-strain, which depended on the extent of simulated bone loss and was critical when the endo-osseous portion of the implant was smaller than the exposed portion. Finally, when implantoplasty is performed under water irrigation, only a minimal increase (max. 1.8°C) in the surrounding tissue temperature was temporarily observed, irrespective of the type of bur used (Sharon et al., 2013; de Souza Júnior et al., 2016).

3.3.2 | Preclinical in vivo studies

No post-operative complications after implantoplasty were reported (Schwarz, Mihatovic, et al., 2014; Schwarz, Sahm, Mihatovic, et al., 2011); a slight to moderate deposition of titanium particles in the adjacent tissues, associated with a localized inflammatory cell infiltrate, was observed histologically 12 weeks post-operatively.

3.3.3 | Clinical studies

No implant loss or other severe complication directly attributed to implantoplasty was reported in any of the clinical studies. In two

TABLE 4 Characteristics and results of the 18 included clinical publications

Study (Year) Study design	Inclusion criteria Aim	Population details: a. Patient No. b. Treatment in IP group c. Implant No. in IP group d. Implant No. in non-IP group e. Follow-up period	Implant details: a. Type (Company) b. Dimension (mm) c. Surface d. Connection e. Location f. Prosthetic restoration	IP details: a. Bur b. Speed c. Cooling d. Cleaning after IP	Complication type & rate as explicitly reported
Suh et al. (2003) Two case reports	Clinical signs of inflammation incl. SoP "The use of IP & guided bone regeneration in the treatment of PI in 2 cases."	a. 2 b. IP + regenerative c. 2 d. 0 e. 6–7 months	a. Straumann ITI (1 solid screw, 1 hollow cylinder) b. 4.1 × 12 c. SLA (1), TPS (1) d. Internal (1), external (1) e. Posterior mand (2) f. Non-loaded (1), FDP (1)	a. Diamond burr (flame-shaped) b. High-speed handpiece c. Copious irrigation d. NR	No complication
Romeo et al. (2005) RCT	PD > 4 mm + horizontal MBL "To compare the clinical outcome of two different surgical approaches for the treatment of PI."	a. 17 b. IP + resective c. 19 d. 16 e. 36 months	a. Straumann ITI (24 solid screws, 11 hollow cylinder) b. NR c. TPS d. Internal & external e. NR f. NR	a. Diamond burs (egg-shaped, 30 & 15 μm) > Arkansas burs > Silicon polishers (Brownie & Greenie) b. 15,000 rpm c. NR d. NR	No implant loss in the IP group No complication
Romeo et al. (2007)[d] RCT	PD > 4 mm + horizontal MBL "To compare the clinical outcome of two different surgical approaches for the treatment of PI."	a. 19 b. IP + resective c. 20 d. 18 e. 36 months	a. Straumann ITI (27 solid screws, 11 hollow cylinder) b. NR c. TPS d. Internal & external e. NR f. NR	a. Diamond burs (egg-shaped, 30 & 15 μm)> Arkansas burs > Silicon polishers (Brownie & Greenie) b. 15,000 rpm c. NR d. NR	No implant loss in the IP group No complication
Schwarz, Sahm, Iglhaut, et al. (2011) RCT	Combined Class I & II defect + PD > 6 mm + intrabony > 3 mm + horizontal MBL ≥ 1 mm "To investigate the impact of two surface decontamination methods on the clinical outcomes of combined surgical treatment of PI."	a. 30 b. IP + regenerative c. 35 d. 0 e. 6 months	a. Ankylos (1), Astra (1), Brånemark (6), Camlog (2), Straumann ITI (9), KSI (1), Nobel Biocare (1), Zimmer (5), Xive (3), non-identifiable (6) b. NR c. NR d. NR e. NR f. SC, FDP	a. Diamond burs > Arkansas stones b. NR c. Copious irrigation with sterile saline d. "Particular care was taken to completely remove any titanium deposits/dust from the surrounding tissues."	No post-operative infection Slight pigmentation of the soft tissue potentially caused by residual titanium particles in one case

(Continues)

TABLE 4 (Continued)

Study (Year) Study design	Inclusion criteria Aim	Population details: a. Patient No. b. Treatment in IP group c. Implant No. in IP group d. Implant No. in non-IP group e. Follow-up period	Implant details: a. Type (Company) b. Dimension (mm) c. Surface d. Connection e. Location f. Prosthetic restoration	IP details: a. Bur b. Speed c. Cooling d. Cleaning after IP	Complication type & rate as explicitly reported
Schwarz et al. (2012)[a] RCT	Combined Class I & II defect + PD > 6 mm + intrabony > 3 mm + horizontal MBL ≥ 1 mm "To investigate the impact of two surface decontamination methods on the clinical outcomes of combined surgical treatment of PI."	a. 24 b. IP + regenerative c. 26 d. 0 e. 24 months	a. Ankylos (1), Astra (1), Brånemark (4), Camlog (1), Straumann ITI (7), KSI (1), Nobel Biocare (1), Zimmer (4), Xive (2), non-identifiable (2) b. NR c. NR d. NR e. NR f. SC, FDP	a. Diamond burs > Arkansas stones b. NR c. Copious irrigation with sterile saline d. "Particular care was taken to completely remove any titanium deposits/dust from the surrounding tissues."	No further complications after the 6-month follow-up
Schwarz et al. (2013)[a] RCT	Combined Class I & II defect + PD > 6 mm + intrabony > 3 mm + horizontal MBL ≥ 1 mm "To investigate the impact of two surface decontamination methods on the clinical outcomes of combined surgical treatment of PI."	a. 21 (additional treatment was required in 4 of them) b. IP + regenerative c. 21 d. 0 e. 48 months	a. Astra (1), Brånemark (4), Camlog (1), Straumann ITI (6), KSI (1), Nobel Biocare (1), Zimmer (3), Xive (2), non-identifiable (2) b. NR c. NR d. NR e. NR f. SC, FDP	a. Diamond burs > Arkansas stones b. NR c. Copious irrigation with sterile saline d. "Particular care was taken to completely remove any titanium deposits/dust from the surrounding tissues."	Two implant losses (due to disease progression and not due to an IP-related complication), otherwise no further complications after the 24-month follow-up
Thierbach and Eger (2013) Prospective case series	PD > 5mm + MBL > 3 mm "To investigate two different types of PI & assess the influence of different treatment measures."	a. 28 b. IP + regenerative c. 17[c] d. 33 e. 3 months	a. "Screw implants" b. NR c. NR d. NR e. NR f. NR	a. "Smoothed & polished" b. NR c. NR d. NR	No post-operative infection No complication
Matarasso et al. (2014) Prospective case series	PD ≥ 5 mm + BoP + ≥2 mm MBL or exposure of ≥1 implant thread "To assess the clinical and radiographic outcomes applying a combined resective and regenerative approach in the treatment of PI."	a. 11 b. IP + regenerative c. 11 d. 0 e. 12 months	a. Straumann TL b. 4.1 (9), 3.3 (2) c. SLA d. Internal e. NR f. SC (5), full-arch reconstructions (4), fixed dental prostheses (2)	a. Egg-shaped diamond burs > Arkansas burs > Silicon polishers (Brownie & Greenie) b. 15,000 rpm c. NR d. Saline solution	No mucosal tattoo No complication

(Continues)

TABLE 4 (Continued)

Study (Year) Study design	Inclusion criteria Aim	Population details: a. Patient No. b. Treatment in IP group c. Implant No. in IP group d. Implant No. in non-IP group e. Follow-up period	Implant details: a. Type (Company) b. Dimension (mm) c. Surface d. Connection e. Location f. Prosthetic restoration	IP details: a. Bur b. Speed c. Cooling d. Cleaning after IP	Complication type & rate as explicitly reported
Schwarz, John, et al. (2014) Single case report	Combined class I & II defect + PD > 6 mm + intrabony 3.7 mm "Clinical outcomes of a combined surgical therapy for advanced PI with concomitant soft tissue volume augmentation using a collagen matrix."	a. 1 b. IP + regenerative +STA c. 1 d. 0 e. 36 months	a. NR b. NR c. NR d. NR e. Posterior mand f. Overdenture	a. Diamond burs > Arkansas stones b. NR c. Copious irrigation with sterile saline d. NR	No post-operative infection No IP-related complication, but due to fracture the bar attachment was replaced by a locator system 15 months after therapy
Schwarz, Sahm, et al. (2014) Prospective case series	Combined Class I & II defect + PD > 6 mm + intrabony > 3 mm + horizontal MBL ≥ 1 mm "To evaluate the clinical outcome of a combined surgical therapy of advanced PI lesions with concomitant soft tissue volume augmentation."	a. 10 b. IP + regenerative +STA c. 13 d. 0 e. 6 months	a. Brånemark (1), Camlog (3), Straumann ITI (5), Zimmer (1), non-identifiable (3) b. NR c. NR d. NR e. NR f. SC, FDP	a. Diamond burs > Arkansas stones b. NR c. Copious irrigation with sterile saline d. NR	No post-operative infection No complication
Schwarz et al. (2015) Retrospective analysis of reentry cases	Combined Class I & II defect + PD > 6 mm + intrabony > 3 mm + horizontal MBL ≥ 1 mm "Report on the clinical defect healing after combined surgical resective/regenerative therapy of advanced PI."	a. 5 b. IP + regenerative c. 5 d. 0 e. 8–78 months	a. NR b. NR c. NR d. NR e. Anterior/posterior max (1/1), anterior/posterior mand (2/1) f. SC, FDP	a. Diamond burs > Arkansas stones b. NR c. Copious irrigation with sterile saline d. NR	No post-operative infection No complication
Pommer et al. (2016) Retrospective case series	PD ≥ 4 mm + BoP + clinical signs of inflammation + MBL "To assess long-term success of PI treatment and the effectiveness of various therapeutic interventions."	a. 142 b. IP + OFD c. 70 d. 72 e. Up to 108 months	a. NR b. NR c. NR d. NR e. NR f. SC (142)	a. Diamond drills b. NR c. NR d. NR	Ten implant losses among the IP treated implants (due to disease progression and not due to an IP-related complication) No complication

(Continues)

TABLE 4 (Continued)

Study (Year) Study design	Inclusion criteria Aim	Population details: a. Patient No. b. Treatment in IP group c. Implant No. in IP group d. Implant No. in non-IP group e. Follow-up period	Implant details: a. Type (Company) b. Dimension (mm) c. Surface d. Connection e. Location f. Prosthetic restoration	IP details: a. Bur b. Speed c. Cooling d. Cleaning after IP	Complication type & rate as explicitly reported
Sapata et al. (2016) Case report	PD ≥ 4 mm + BoP + MBL > 2 mm Case description	a. 1 b. IP + OFD c. 2 d. 4 e. 24 months	a. NR b. NR c. Rough d. External hexagon e. Max (6) f. Full-arch fixed prosthesis before & overdenture after surgery	a. Diamond burs > Arkansas burs > Silicon polishers b. 15,000 rpm c. Constant cooling with sterile saline d. CHX	No post-operative infection No complication
Geremias et al. (2017) Case report	"high level of bone loss" "To analyze the planktonic growth of Streptococcus mutans on the surfaces of 3 implants retrieved after 3 different PI treatments."	a. 1 b. NR c. 1 d. 2 e. 4 months	a. Neodent (3) b. 4.1 × 9 c. Dual acid-etched d. External hexagon e. NR f. Non-loaded	a. "according to the Schwarz protocol" b. NR c. NR d. NR	No complication until planned explantation after 4 months
Schwarz et al. (2017)[a] RCT	Combined Class I & II defect + PD > 6 mm + intrabony > 3 mm + horizontal MBL ≥ 1 mm "To investigate the impact of two surface decontamination methods on the clinical outcomes of combined surgical treatment of PI."	a. 15 b. IP + regenerative c. 15 d. 0 e. 84 months	a. Astra (1), Brånemark (1), Camlog (1), Straumann ITI (5), KSI (1), Nobel Biocare (1), Zimmer (2), Xive (1), non-identifiable (2) b. NR c. NR d. NR e. NR f. SC, FDP	a. Diamond burs > Arkansas stones b. NR c. Copious irrigation with sterile saline d. "Particular care was taken to completely remove any titanium deposits/dust from the surrounding tissues."	No mucosal tattoo No implant fracture No further complications after the 48-month follow-up
Englezos et al. (2018) Prospective case series	PD ≥ 6 mm "Outcome of resective surgery incl. apically positioned flap combined with osteoplasty & IP."	a. 25 b. IP + resective c. 40 d. 0 e. 48 months	a. Nobel Biocare (17), Straumann & Ankylos (8 each), Astra, Zimmer & IMZ (2 each), Biomet3i (1) b. NR c. Moderately rough d. NR e. Anterior/posterior max (8/14), anterior/posterior mand (9/9) f. SC (8), FDP (13), complete fixed dentures (13), overdentures (6)	a. Diamond burs > Arkansas stones > brown & green polishing rubber flame-shaped burs b. NR c. "Under irrigation" d. CHX, saline solution	No complication

(Continues)

TABLE 4 (Continued)

Study (Year) Study design	Inclusion criteria Aim	Population details: a. Patient No. b. Treatment in IP group c. Implant No. in IP group d. Implant No. in non-IP group e. Follow-up period	Implant details: a. Type (Company) b. Dimension (mm) c. Surface d. Connection e. Location f. Prosthetic restoration	IP details: a. Bur b. Speed c. Cooling d. Cleaning after IP	Complication type & rate as explicitly reported
Nart et al. (2018) Prospective case series	2-/3-wall infrabony defects ≥ 3 mm of depth + PD > 5 mm + BoP and/or SoP "To assess the clinical and radiographic outcomes of the regenerative treatment of PI using a vancomycin & tobramycin impregnated allograft."	a. 13 b. IP + regenerative c.17 d. 0 e. 12 months	a. Nobel Biocare (6), Avinent (5), Klockner (4), Biohorizons (2) b. NR c. NR d. NR e. Mand (10), max (7) f. SC (10), FDP (7) – screw-retained (13), cemented (4)	a. Diamond bur (40- & 15- µm grit size)> Arkansas stone b. NR c. NR d. Saline solution	No post-operative infection No complication
Ramanauskaite et al. (2018)[b] Retrospective case series	MBL + BoP and/or SoP "To compare the clinical outcomes following combined surgical treatment of PI at initially grafted and non-grafted implant sites."	a. 39 b. IP + regenerative c. 57 d. 0 e. 6–126; average 42 months	a. Solid screw (one or two part) titanium implant b. NR c. NR d. NR e. Max (26), mand (31), anterior (15), posterior (42) f. Fixed or removable implant-supported prostheses	a. Diamond burs > Arkansas stones b. NR c. Copious irrigation with sterile saline d. NR	No complication

Abbreviations: BoP, bleeding on probing; CHX, chlorhexidine; FDP, fixed dental prosthesis; IP, implantoplasty; mand, mandible; max, maxilla; MBL, marginal bone loss; NR, not reported; OFD, open flap debridement; PD, probing pocket depth; PI, peri-implantitis; RCT, randomized controlled clinical trial; SC, single crowns; SLA, sandblasted acid-etched; SoP, suppuration on probing; STA, soft tissue augmentation; TL, tissue level; TPS, titanium plasma spray.

[a]Follow-up of Schwarz, Sahm, Iglhaut, et al. (2011).

[b]Some patients were part of Schwarz, Sahm, Iglhaut, et al. (2011).

[c]Unclear whether all 17 implants received IP.

[d]Mainly same patients as in Romeo et al. (2005).

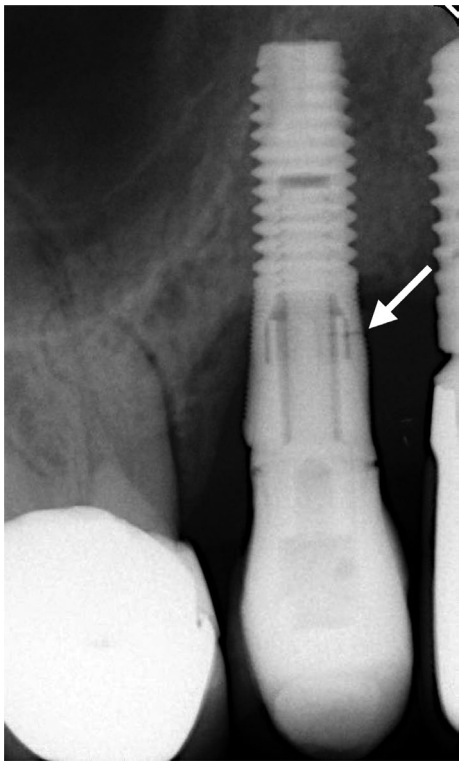

FIGURE 3 Clinical case from authors' clinic illustrating a fracture at the implant collar (white arrow), at a single implant in the premolar region of the maxilla, approximately 3 years after implantoplasty

studies, a total of 12 implant losses during follow-up—due to disease progression—were reported (Pommer et al., 2016; Schwarz et al., 2013). In one study (Schwarz, Mihatovic, et al., 2014), a fracture of a bar attachment 15 months post-operatively was observed, but it did not appear related to implantoplasty. Finally, the only complication that was attributed to implantoplasty was a slight pigmentation of the soft tissue in a single patient due to titanium particle deposition from grinding (Schwarz, Sahm, Iglhaut, et al., 2011).

4 | DISCUSSION

The present systematic review focused on possible mechanical and/or biological complications after implantoplasty. Based on all currently available, yet limited, preclinical in vivo and clinical evidence, implantoplasty appears not associated with any remarkable mechanical or biological complications.

Due to the subtractive nature of implantoplasty, it is reasonable to consider the possibility of various mechanical complications either during the procedure (e.g., perforation of the implant body or destruction of the implant-abutment connection) or at a later stage (e.g., implant collar deformation and loosening of the supra-structure, fixation-screw fracture, implant fracture). While the complications during the procedure might be avoidable, if care is taken, the late complications might not be able to control, as they are depended on the altered (weakened) mechanical properties of the implant. Indeed, the laboratory studies included in this review have indicated that narrow/standard—but not wide—diameter implants suffer from a variable, mostly significant, extent of weakening due to implantoplasty (Chan et al., 2013; Costa-Berenguer et al., 2018; Gehrke et al., 2016). In this context, the information regarding the clinical performance of implants subjected to implantoplasty is based on relatively limited numbers, with short- to medium-term follow-up, which may be considered as limitation of the current review. In particular, in the available studies reporting on about 200–300 implants subjected to implantoplasty, specific information regarding implant dimensions was available for only about 15 implants—from those only two were narrow (i.e., 3.3 mm) and followed for only 1 year—while the information available regarding the implant design, type of connection (e.g., external-hex or morse taper), type of reconstruction (e.g., single crowns, overdenture, fixed dental prosthesis, number of implants replacing how many units, etc.), jaw region, and opposing dentition (e.g., teeth, dentures, or implant-born reconstructions) was not always clear, if reported at all. Implant design and type of connection are important in terms of the mechanical properties after implantoplasty, since they define the remaining implant wall thickness and strain distribution, and consequently the bending and fracture strength of the implant-fixation screw-abutment system. This was clearly demonstrated in one of the included laboratory studies, where implants with the same macro-geometry and size (4 mm in diameter), but different connection type, showed marked differences in bending strength reduction (i.e., ranging from 20% to 40%) after implantoplasty (Gehrke et al., 2016). Further, the strains exerted at the implant-fixation screw-abutment system depend—among other factors—on the region of the mouth, the type of reconstruction, and the opposing dentition. For example, lower forces are usually observed in the anterior regions of the mouth and when the opposing dentition is fixed partial dentures on teeth, comparing to posterior regions and when the opposing dentition is implant-borne reconstructions (Hämmerle et al., 1995; Vallittu & Könönen, 2000). Thus, a single posterior narrow implant, subjected to implantoplasty, would be at higher risk for mechanical complications compared with a 3-unit bridge on two standard diameter implants in the anterior region. Nevertheless, despite that the available information is limited and incomplete, and secure conclusions may not be drawn, based on the facts that the implants in the included clinical studies (a) were of different brands/systems, thus representing different connection types, (b) were placed in various positions in the mouth, implying most likely use of not only wide diameter implants, (c) represented different type of reconstructions, including single crowns, (d) about half of them were followed for about 4 years, and (e) basically did not suffer from any remarkable mechanical complications, it is reasonable to claim that, in praxis, implantoplasty does not appear to significantly compromise the mechanical properties of implants, at least on the short- to medium-term; nevertheless, mechanical complications cannot be definitely excluded (Figure 3).

Except from mechanical complications, it is reasonable to consider also the possibility of biological complications, either during the procedure (i.e., overheating of the implant during grinding causing thermal damage to the surrounding bone) or at a later stage (i.e., induction of mucosal staining and/or increased risk for inflammatory reactions due to titanium particle deposition, generated from the grinding procedure). It is known that increase in temperature between 42 and 45°C results in reversible heat-shock (Li, Chien, & Brånemark, 1999), but the threshold for irreversible thermal damage to the bone is 47°C for 1 min (Eriksson & Albrektsson, 1983). Indeed, studies assessing the impact of implant-abutment grinding on temperature levels at the implant/bone interface have shown that, depending on the type of bur used and the contact time of the bur with the abutment, there is quite some variation in temperature increase, but under standard water cooling from the dental unit the temperature remains generally below the threshold of thermal damage (Brägger, Wermuth, & Török, 1995; Gross, Laufer, & Ormianar, 1995; Huh, Eckert, Ko, & Choi, 2009). During implantoplasty, however, the grinding is performed directly on the implant; thus, temperature increases at the implant/bone interface may be different (i.e., higher) than what observed in the studies involving abutment grinding. In the two laboratory studies identified herein, temperature increase at the implant/bone interface during implantoplasty under standard water cooling was momentarily < 2°C, irrespective the type of bur or duration of grinding (Sharon et al., 2013; de Souza Júnior et al., 2016), that is, well below the 47°C threshold. Thus, overheating of the neighboring bone tissue during implantoplasty appears easy to control by means of standard cooling and does not pose any concern in terms of osseous thermal damage. In contrast, deposition of titanium particles to the neighboring hard and soft tissues due to grinding is more difficult to control and variable amounts of such particles should be expected remaining in the tissues surrounding the implant after implantoplasty. Indeed, in one of the clinical studies included herein, a single case of slight mucosal pigmentation, attributed to titanium particle deposition from the grinding, was observed (Schwarz, Sahm, Iglhaut, et al., 2011). Concerns have indeed been raised, based on results of in vitro studies, regarding the possible role of titanium particles in peri-implant tissues in terms of initiation or aggravation of inflammatory processes (Noronha Oliveira et al., 2018). In the only preclinical in vivo study identified that involved implantoplasty (Schwarz, Mihatovic, et al., 2014; Schwarz, Sahm, Mihatovic, et al., 2011), presence of titanium particles in the surrounding soft tissues was associated with only a limited extent, low grade, chronic inflammatory response. Further, except from the above-mentioned single case of tissue discoloration, no clinical study included in this review mentioned any other adverse event related to titanium particle deposition, despite the variable type of burs used and most likely the variable amount of deposition. In this context, a very recent consensus report concluded that on the basis of the available evidence, although the possibility cannot unequivocally be excluded, it is not likely that titanium particles elicit adverse biological reactions in the peri-implant tissues (Schliephake et al., 2018).

In perspective, the focus of this review was on possible mechanical and/or biological complications of implantoplasty; thus, no attempt was made to particularly assess the efficacy of the procedure in general, or depending on the way it is performed, for example, which type of burs is used to grind/smoothen the implant surface, or whether implantoplasty is used as single approach or combined with a resective or regenerative approach. Nevertheless, it has to be mentioned that based on the currently available—relatively weak—evidence, implantoplasty appears to yield positive clinical and radiographic results, that is, low bleeding rates, shallow probing pocket depths, increased clinical attachment levels, and increased or stable bone levels on the short- to medium-term (Matarasso et al., 2014; Pommer et al., 2016; Romeo et al., 2005, 2007; Schwarz et al., 2013; Schwarz, Sahm, Iglhaut, et al., 2011).

In conclusion, based on an appraisal of all currently available, yet limited, preclinical in vivo and clinical evidence, implantoplasty seems not associated with any remarkable mechanical or biological complications on the short- to medium-term. The effectiveness of implantoplasty for the management of peri-implantitis has yet to be determined.

ACKNOWLEDGEMENTS

Partial funding for the review was provided from KOF/Calcin Foundation of the Danish Dental Association and from the Austrian Society of Implantology (ÖGI).

CONFLICT OF INTEREST

All authors declare no conflict of interest.

AUTHOR CONTRIBUTION

A.S. and K.B. conceived the ideas; S.E and K.B. collected the data; S.E. and K.B. analyzed the data; and A.S. K.B, and K.G. led the writing.

ORCID

Andreas Stavropoulos https://orcid.org/0000-0001-8161-3754
Kristina Bertl https://orcid.org/0000-0002-8279-7943

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

How to cite this article: Stavropoulos A, Bertl K, Eren S, Gotfredsen K. Mechanical and biological complications after implantoplasty—A systematic review. *Clin Oral Impl Res*. 2019;30:833–848. https://doi.org/10.1111/clr.13499